Status of an Alternative Measurement of the Inclusive Muon Neutrino Charged-current Cross Section in the NOvA Near Detector

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Fermilab, USA

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Fermilab
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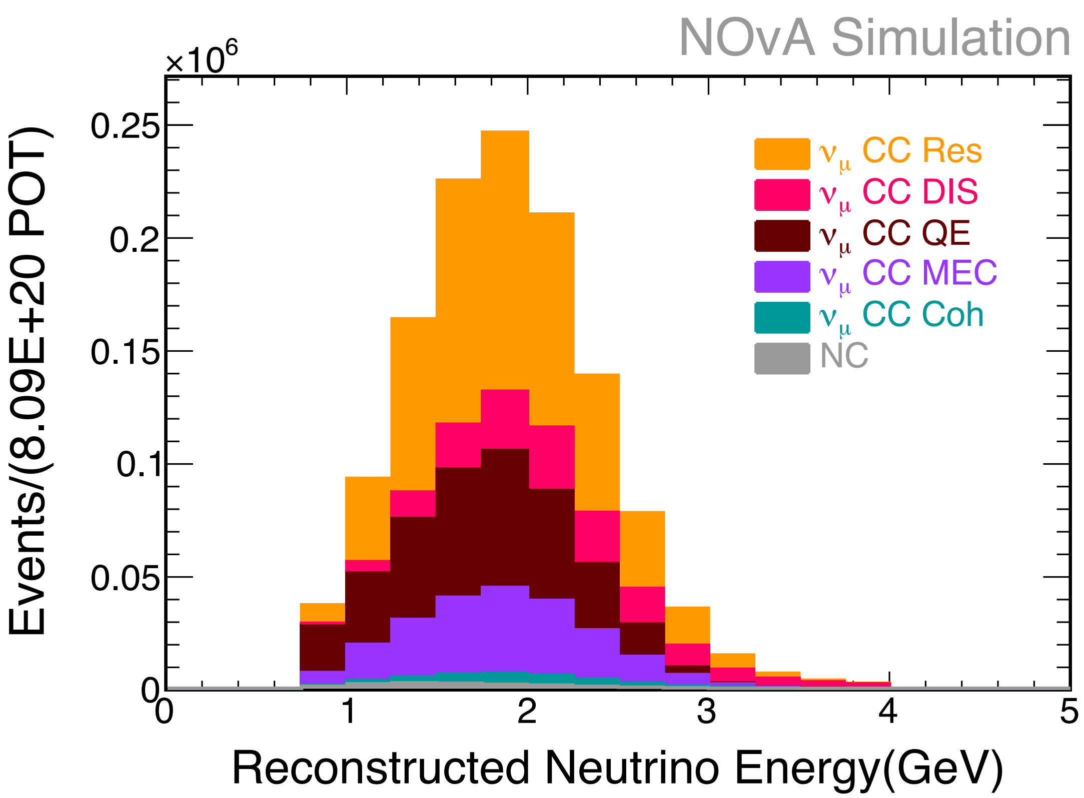
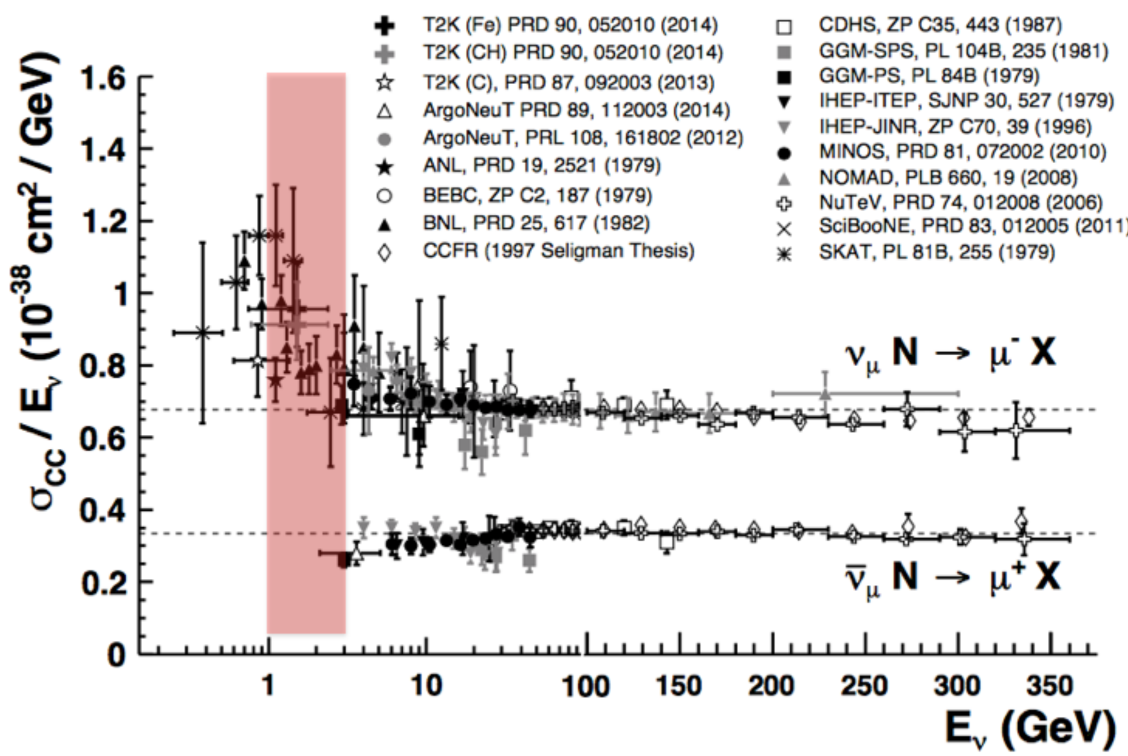
Motivation

- Long-baseline neutrino experiments are entering in the precision era, need to reduce systematic errors to the level of few percent.

- The ν_μ charge current inclusive process is a baseline measurement, one that can be used to directly tune our simulation for the oscillation analysis and can be used for cross-section ratio measurements with reduced systematic.





C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

- Improving the precision of our oscillation measurement requires better knowledge of neutrino-nucleus cross-section.

Motivation

- Long-baseline neutrino experiments are entering in the precision era, need to reduce systematic errors to the level of few percent.

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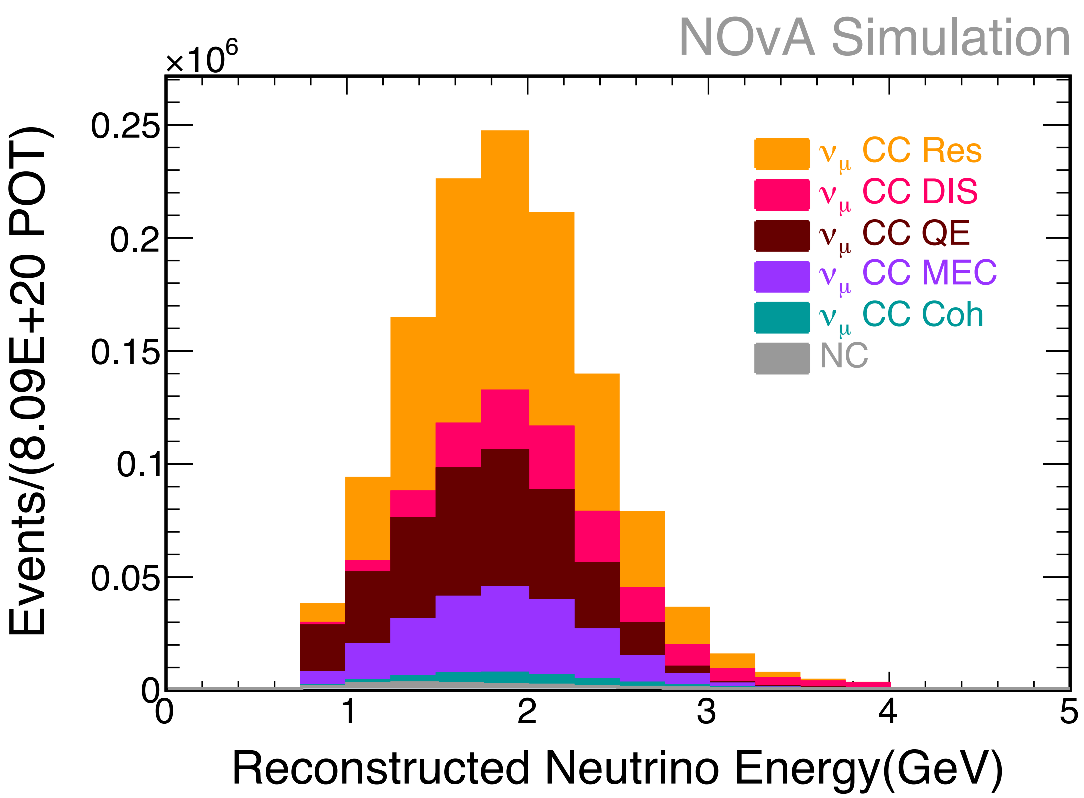
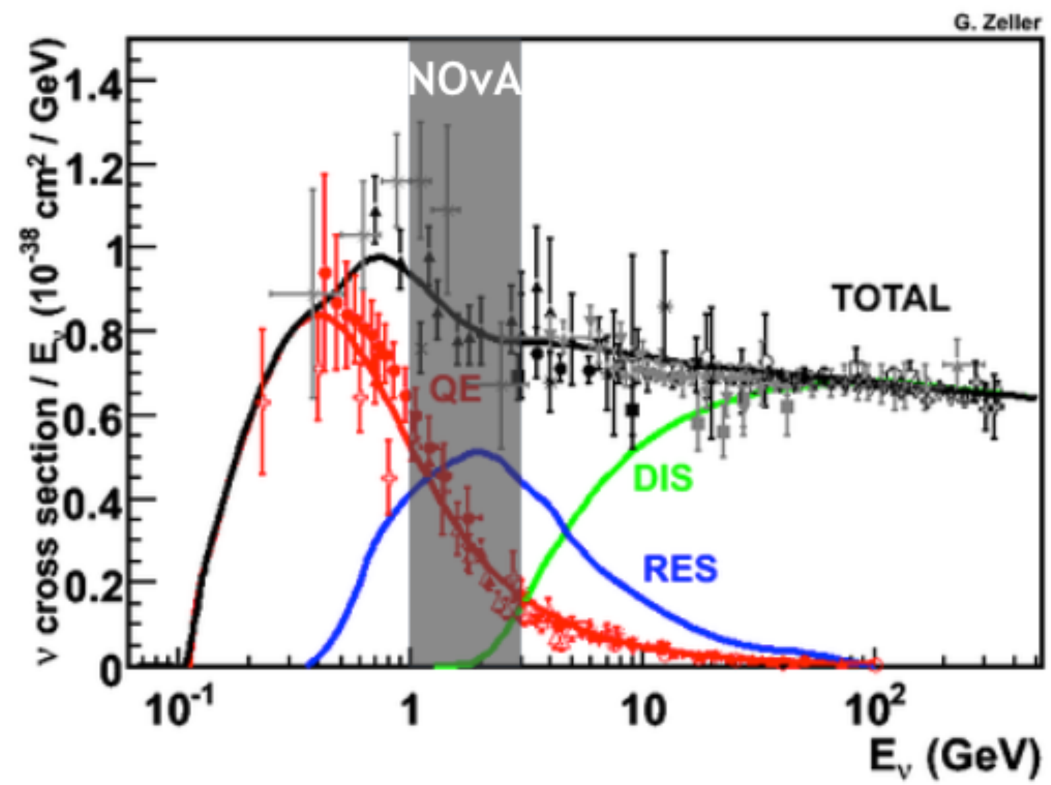


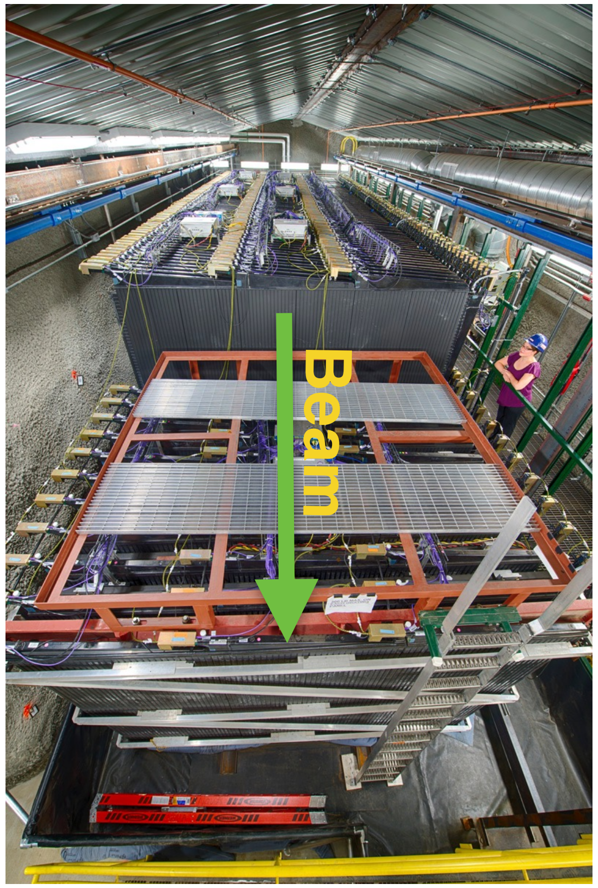


- Improving the precision of our oscillation measurement requires better knowledge of neutrino-nucleus cross-section.

NuMI Off-axis ν_e Appearance

NOvA is a long-baseline oscillation experiment

Uses NuMI muon neutrino beam from Fermilab



Near Detector (ND) is 1km from the source

Underground (100m from surface)

14.6 mrad off-axis w.r.t NuMI beam, peaked at 2 GeV ν energy

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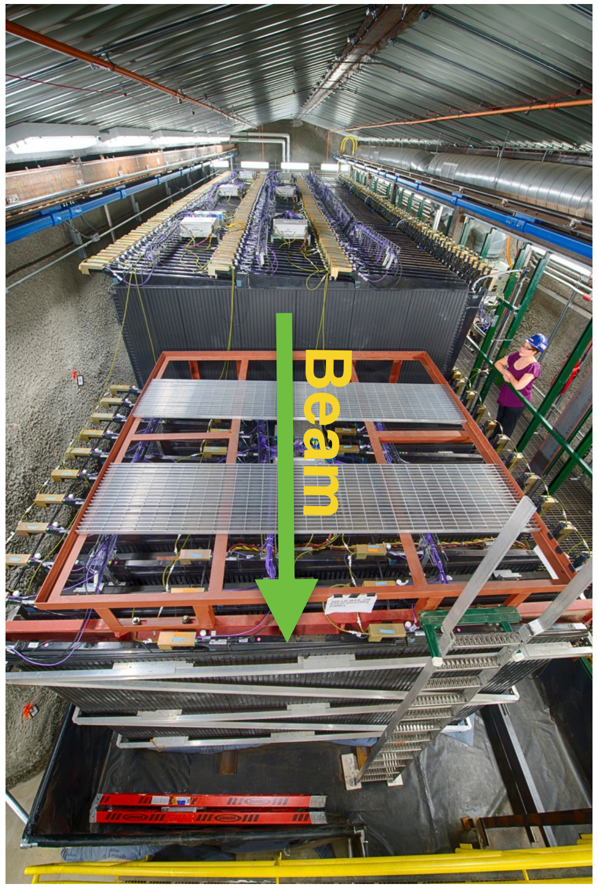
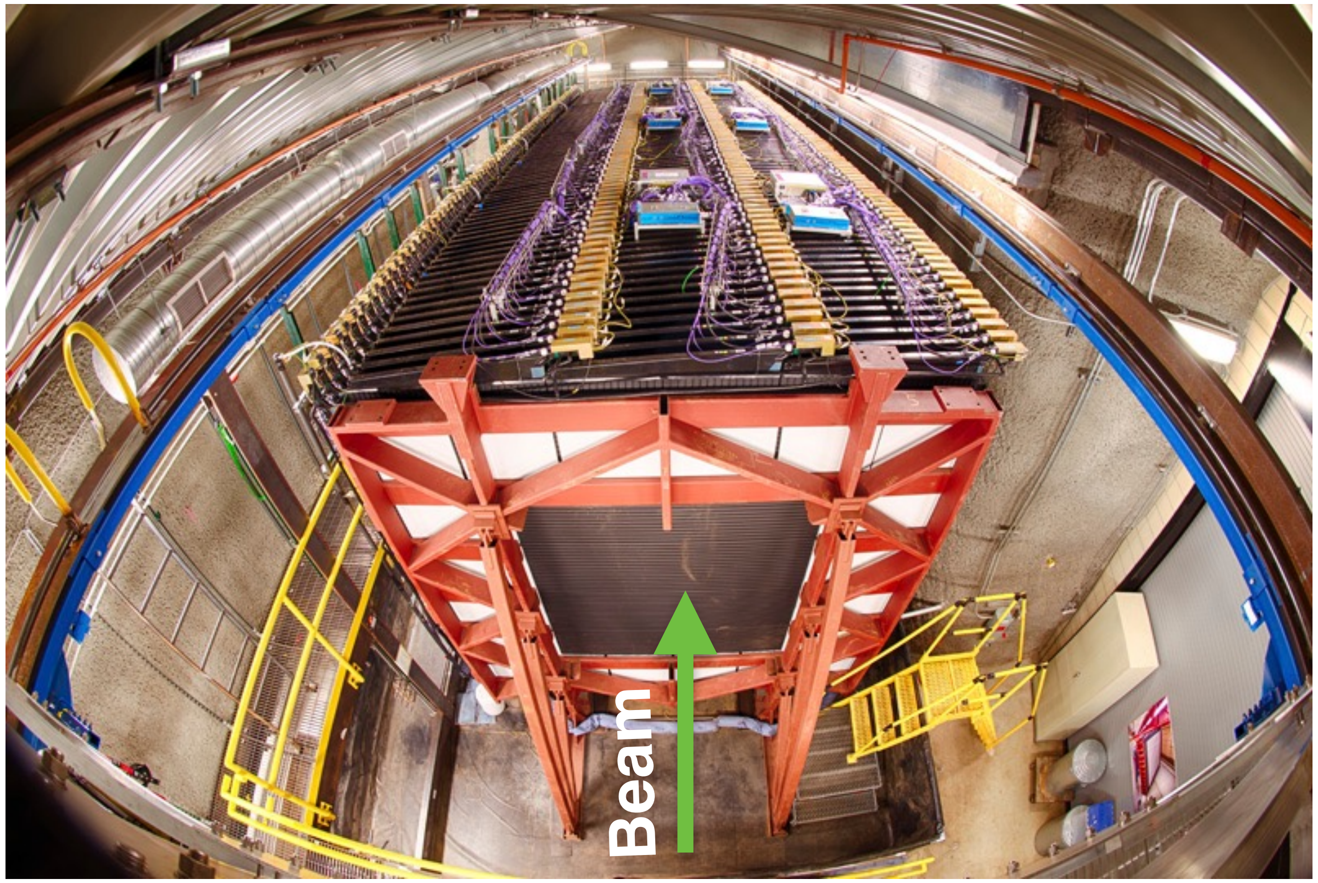


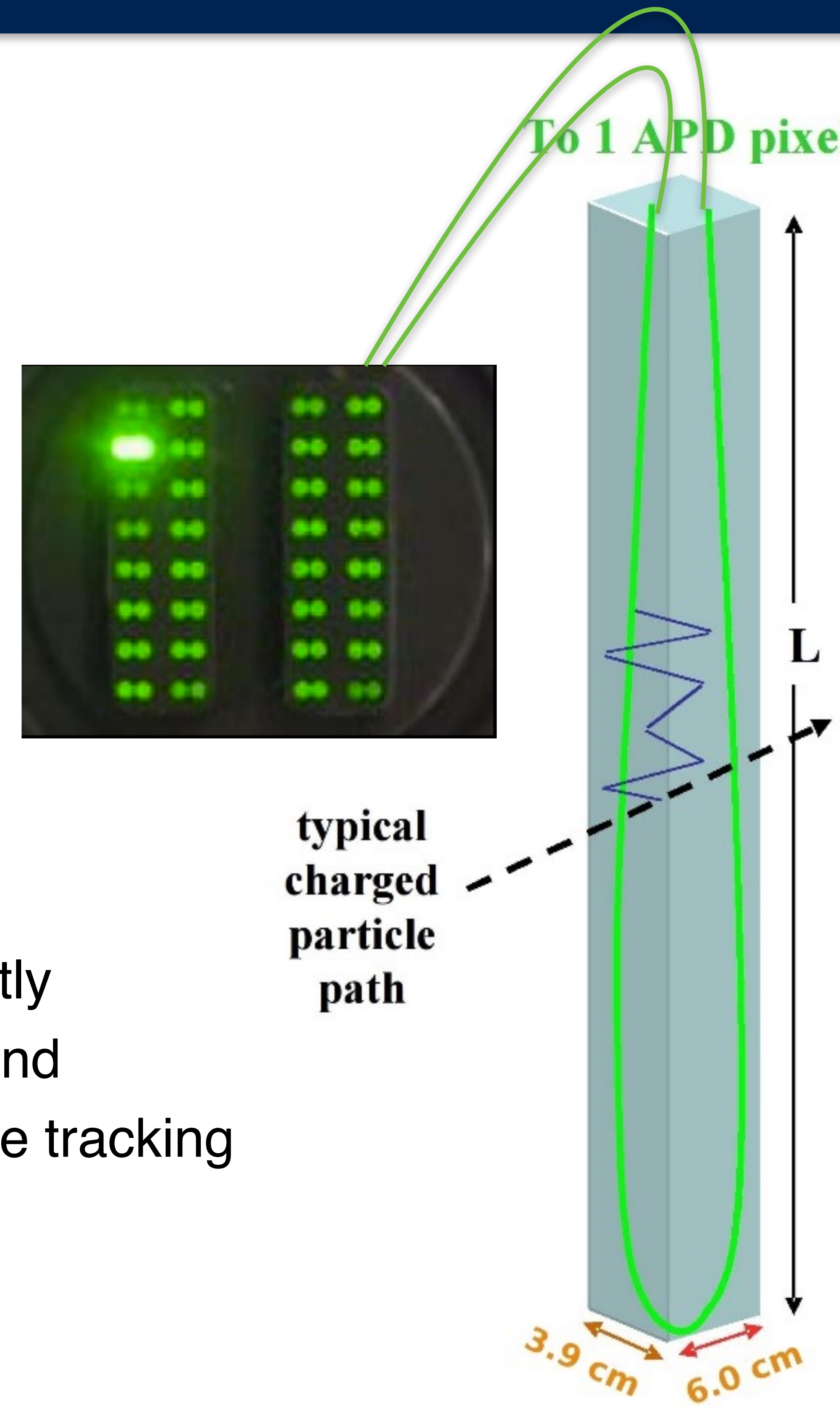
NOvA ND :

- 3.9m X 3.9m X 12.67m
- 193 ton, 18k channels
- 192 planes

At the back end of detector alternating steel planes with active cells.
Increases the efficiency to contain muons

NuMI Off-axis ν_e Appearance





- Active cells made up of PVC with liquid scintillator (mostly Carbon). Low-Z (nicely separation between long track and electromagnetic shower), 1 plane ~ $0.15X_0$, highly active tracking calorimeter.
- Use to measure composition of the un-oscillated beam, In addition to that it provides very good opportunity for cross-section measurement.

Cross-section Measurement in the NOvA Near Detector

- We will measure the inclusive cross section in bins of true neutrino energy and as well as flux-integrated double differential with respect to the final state muons true kinetic energy and true angle.

$$\left(\frac{d^2\sigma}{d\cos\theta_\mu dT_\mu}\right)_i = \frac{\sum_j U_{ij}(N^{\rm sel}(\cos\theta_\mu, T_\mu)_j - N^{\rm bkg}(\cos\theta_\mu, T_\mu)_j)}{\epsilon(\cos\theta_\mu, T_\mu)_i(\Delta\cos\theta_\mu)_i(\Delta T_\mu)_i N_{\rm target}\Phi}$$

N^{sel} : Number of selected counts

N^{bkg} : Number of estimated background counts

U : Unfolding matrix that corrects the reconstructed quantities for detector resolution

Φ : The neutrino flux

ϵ : Signal selection efficiency

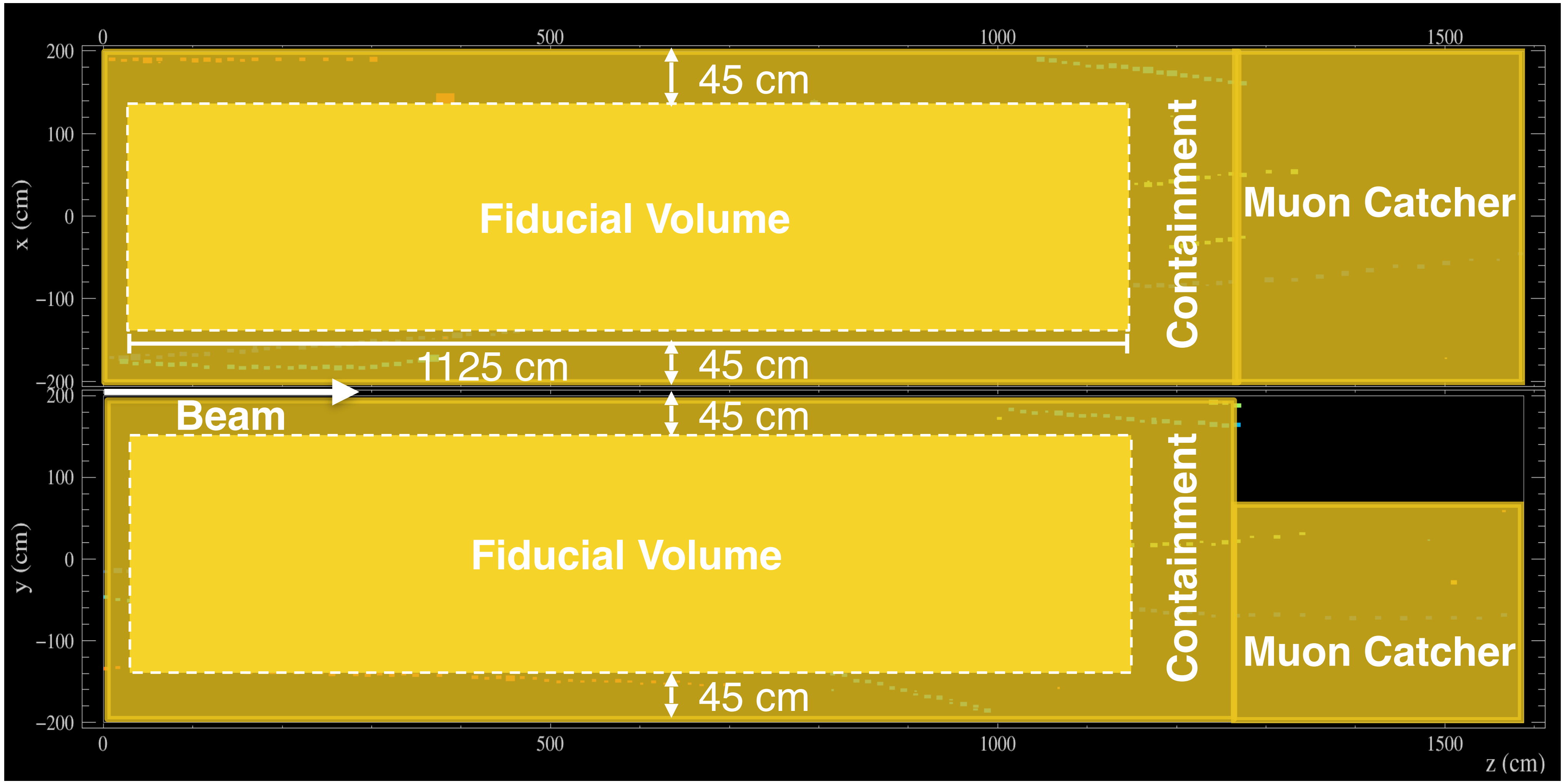
N_{target} : The number of targets in the fiducial volume

$(\Delta\cos\theta_\mu)_i$: Bin width for true angle

$(\Delta T_\mu)_i$: Bin width for true muon kinetic energy

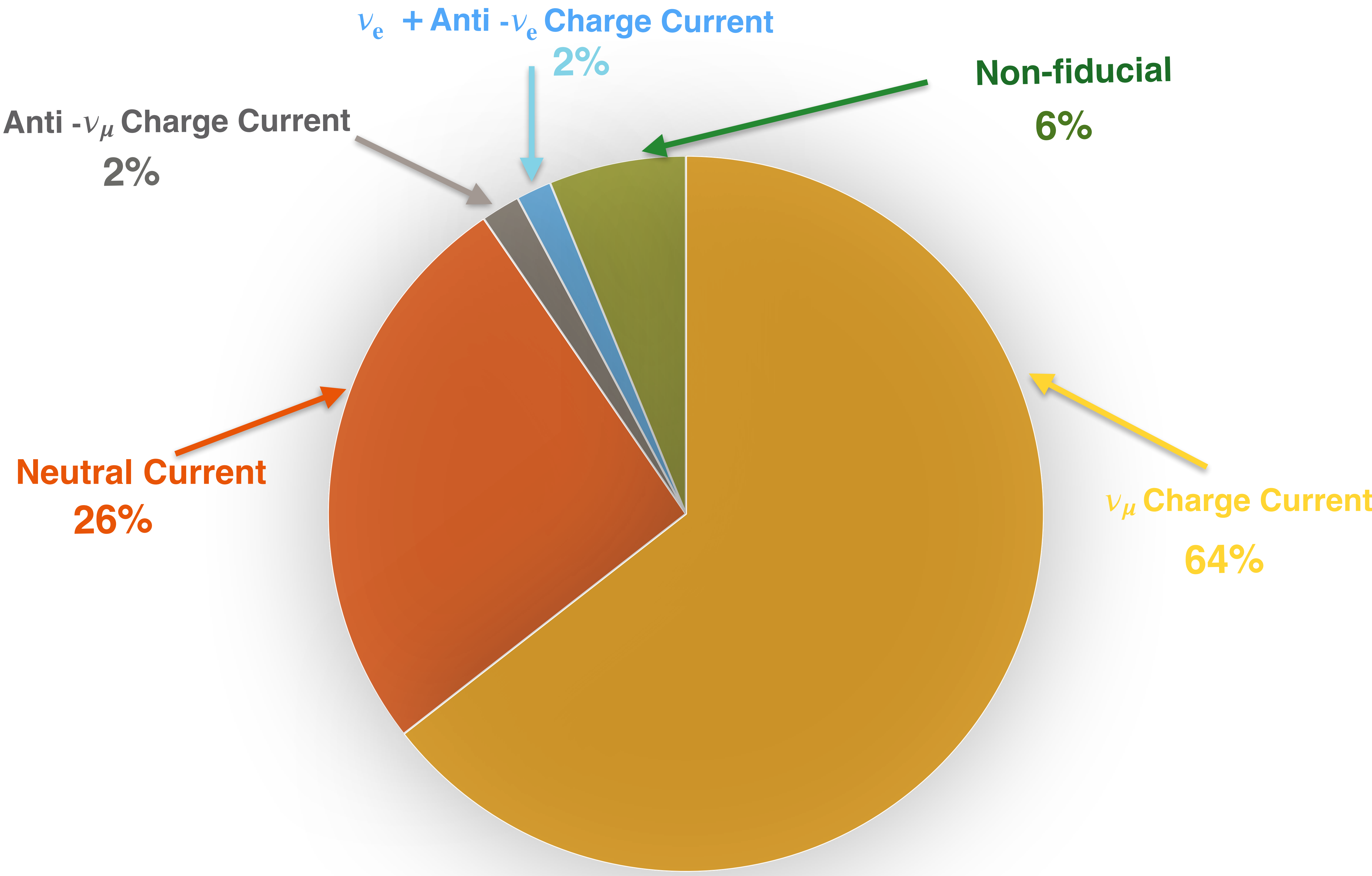
Event Preselection

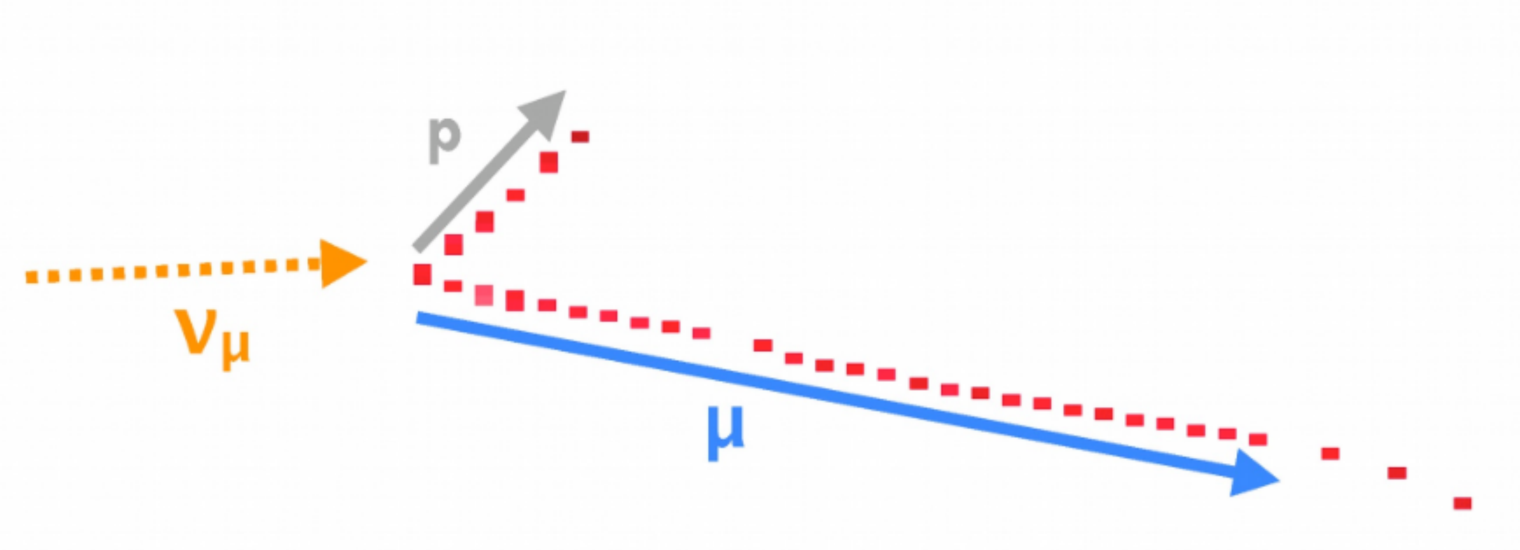
- Beam spill quality, detector and event quality cuts.
  - Beam positioning, horn current range, minimum spill POT (proton on target), maximum time to nearest spill
- We required that all track vertices start inside the fiducial volume.

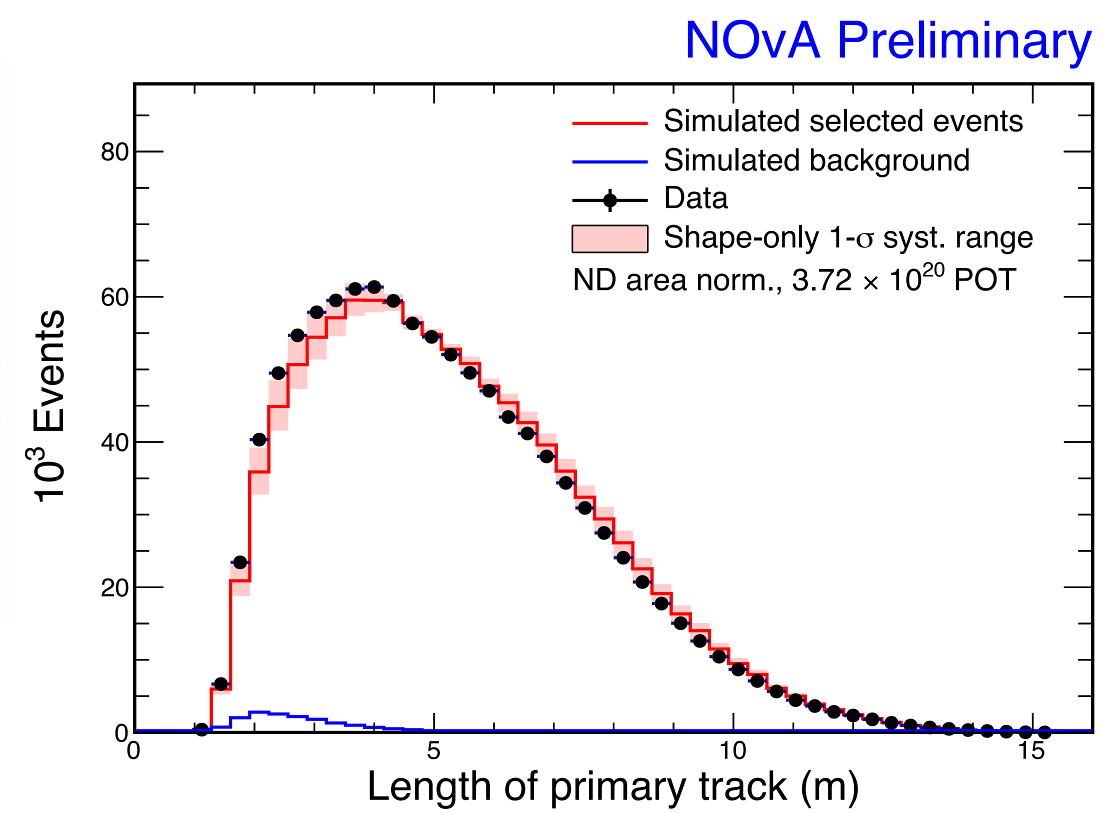


- Cuts are designed to reject energy deposited by neutrino interactions in the surrounding rock.

Event Counts After Preselection

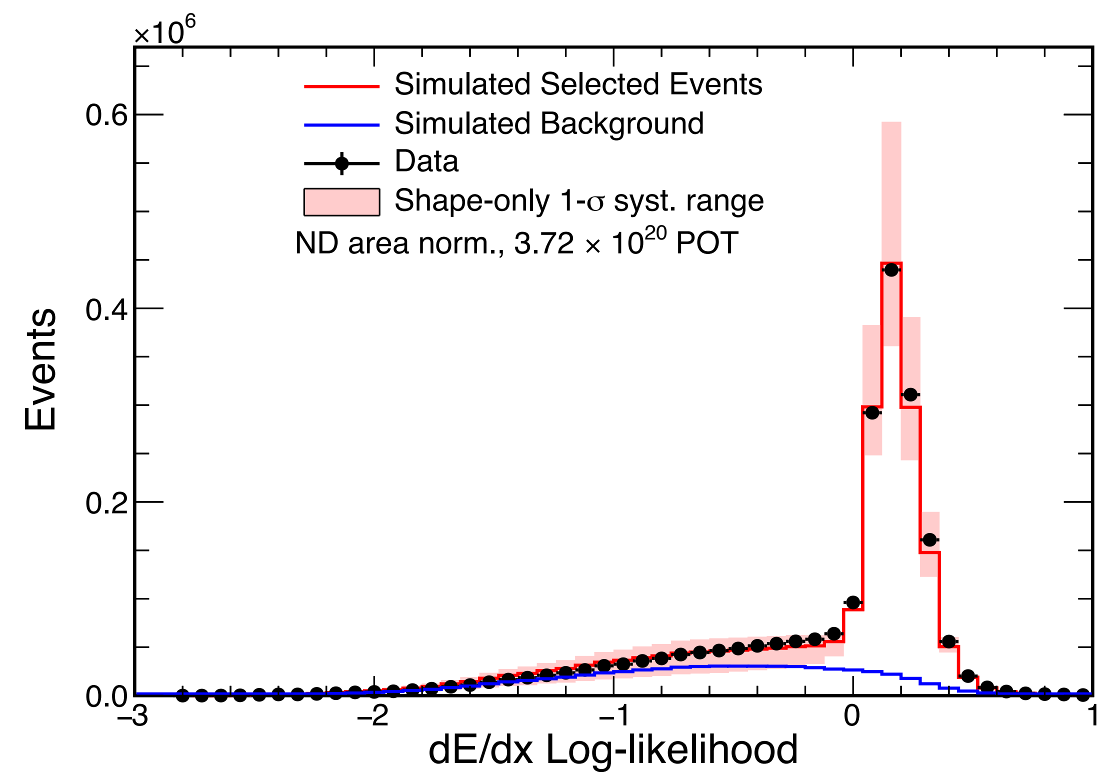




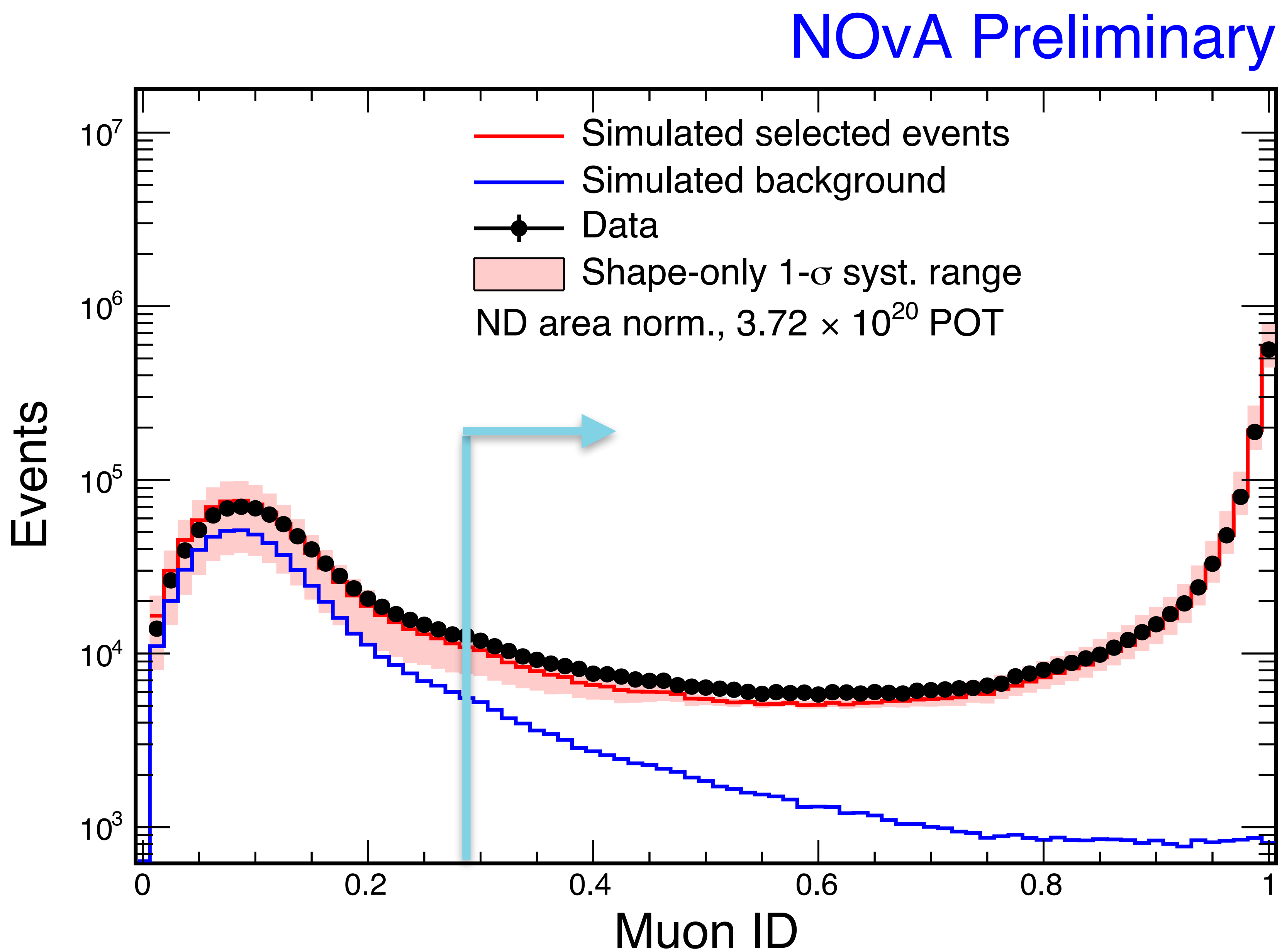


- NOvA reconstructs muons as tracks and separates them from the hadronic background using a **k-nearest neighbors (kNN)** algorithm trained with four variables:

  - track length
  - longitudinal energy profile (dE/dx)
  - scattering along the track and
  - fraction of energy in the neutrino event associated with the track



Event Selection



Events with **Muon ID > 0.29** (Optimized Muon ID w.r.t different interaction type by using F.O.M ($\frac{s}{\sqrt{s+b}}$) are retained as candidate of ν_μ CC events.

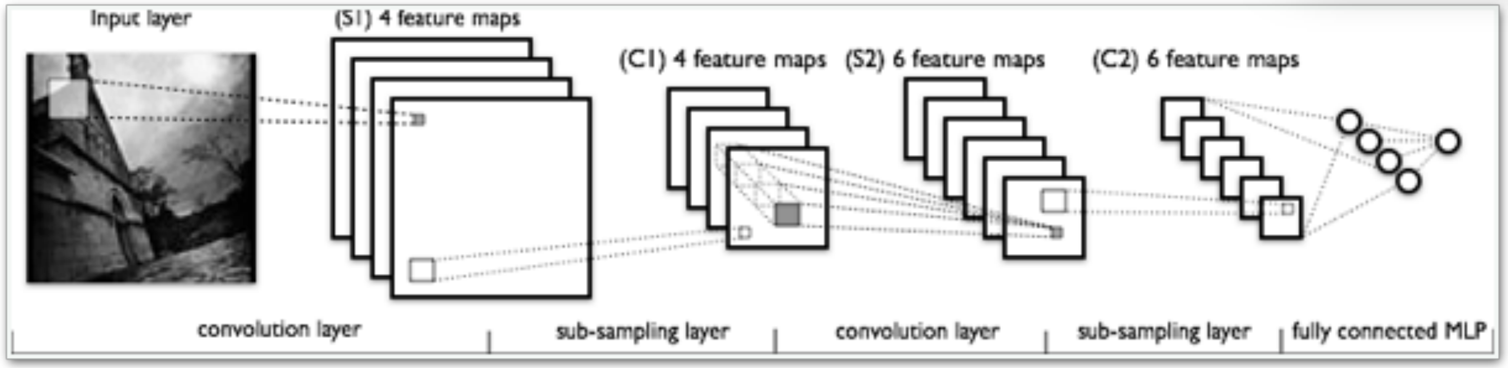
Why it’s an Alternative Measurement ?

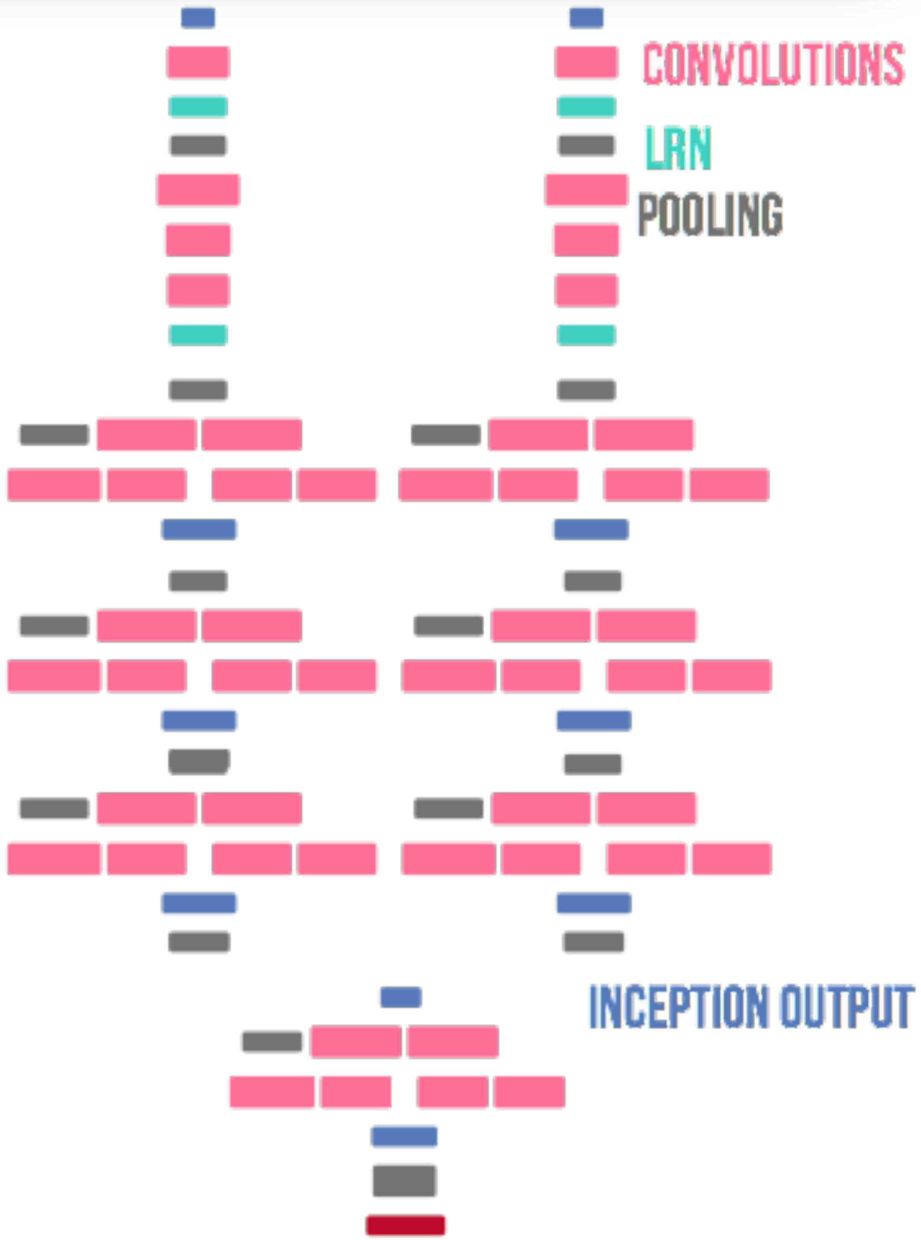
Event Identification using Convolutional Visual Network (CVN)

NOvA classifies events based on Deep Neural Network.

NOvA's nue appearance analysis is the first implementation of a CNN in a HEP result.

x4.7 million





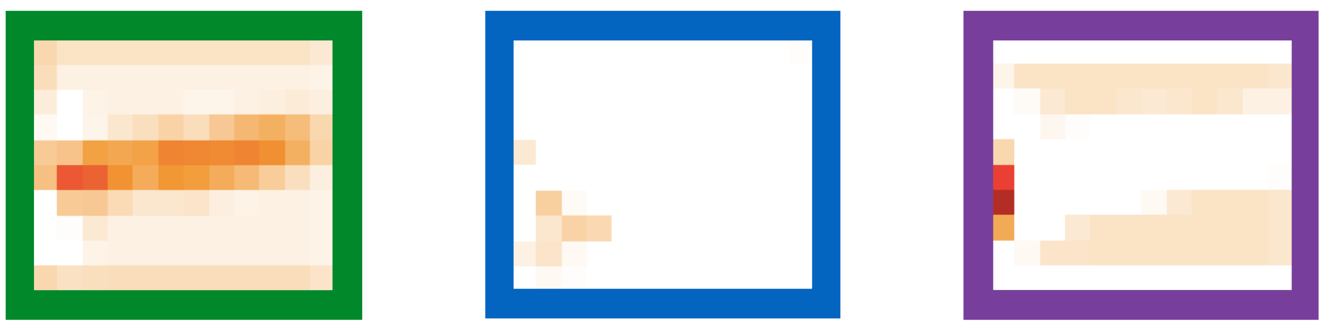
- **CVN is an event classifier which employs a Deep Convolutional Network in the "image recognition" style.**
- **The network is trained on two dimensional views of the event's calibrated hits.**
- **The information of each view is then combined in the final layers of the network.**

Event Identification using Convolutional Visual Network (CVN)

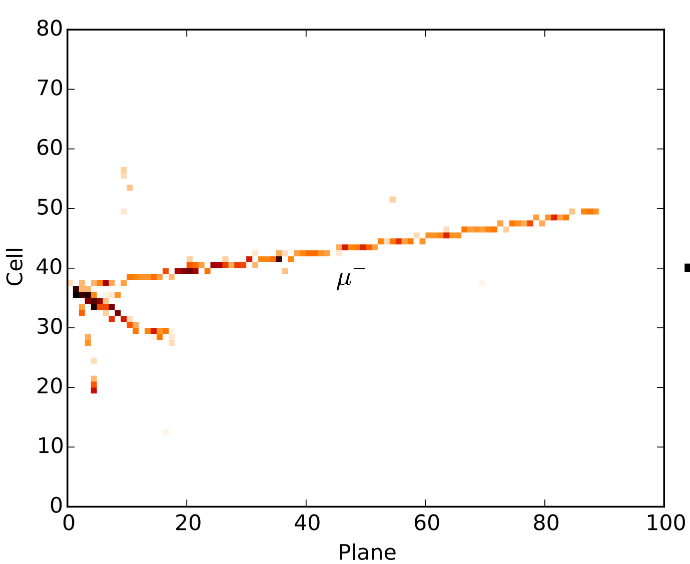
Calibrated hit maps are inputs to Convolutional Visual Network (CVN)

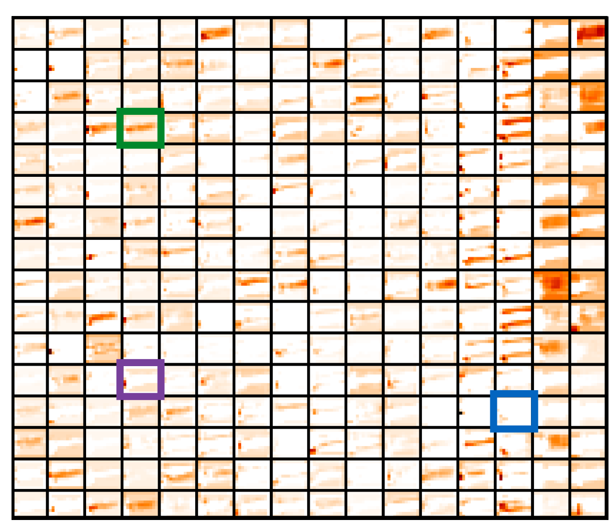
Series of image processing transformations applied to extract abstract features

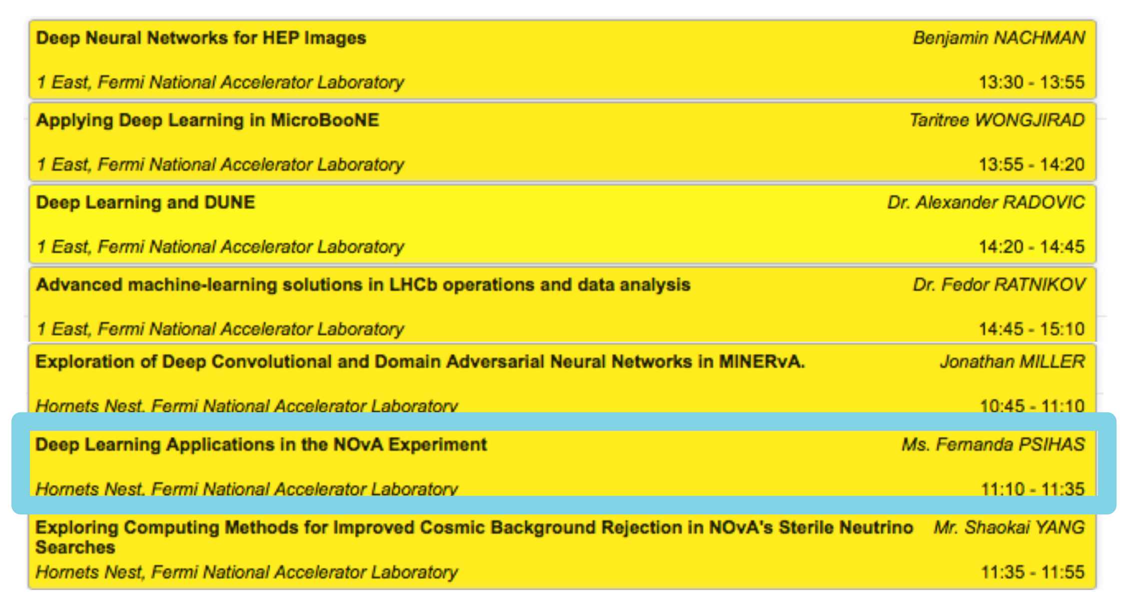
Extracted features used as inputs to a conventional neural network to classify the events.



“A Convolutional Neural Network Neutrino Event Classifier”
A. Aurisano et. al., JINST 11 (2016) no.09, P09001







Deep Neural Networks for HEP Images	Benjamin NACHMAN
1 East, Fermi National Accelerator Laboratory	13:30 - 13:55
Applying Deep Learning in MicroBooNE	Taritree WONGJIRAD
1 East, Fermi National Accelerator Laboratory	13:55 - 14:20
Deep Learning and DUNE	Dr. Alexander RADOVIC
1 East, Fermi National Accelerator Laboratory	14:20 - 14:45
Advanced machine-learning solutions in LHCb operations and data analysis	Dr. Fedor RATNIKOV
1 East, Fermi National Accelerator Laboratory	14:45 - 15:10
Exploration of Deep Convolutional and Domain Adversarial Neural Networks in MINERvA.	Jonathan MILLER
Hornets Nest, Fermi National Accelerator Laboratory	10:45 - 11:10
Deep Learning Applications in the NOvA Experiment	Ms. Fernanda PSIHAS
Hornets Nest, Fermi National Accelerator Laboratory	11:10 - 11:35
Exploring Computing Methods for Improved Cosmic Background Rejection in NOvA's Sterile Neutrino Searches	Mr. Shaokai YANG
Hornets Nest, Fermi National Accelerator Laboratory	11:35 - 11:55

ν_μ CC Event

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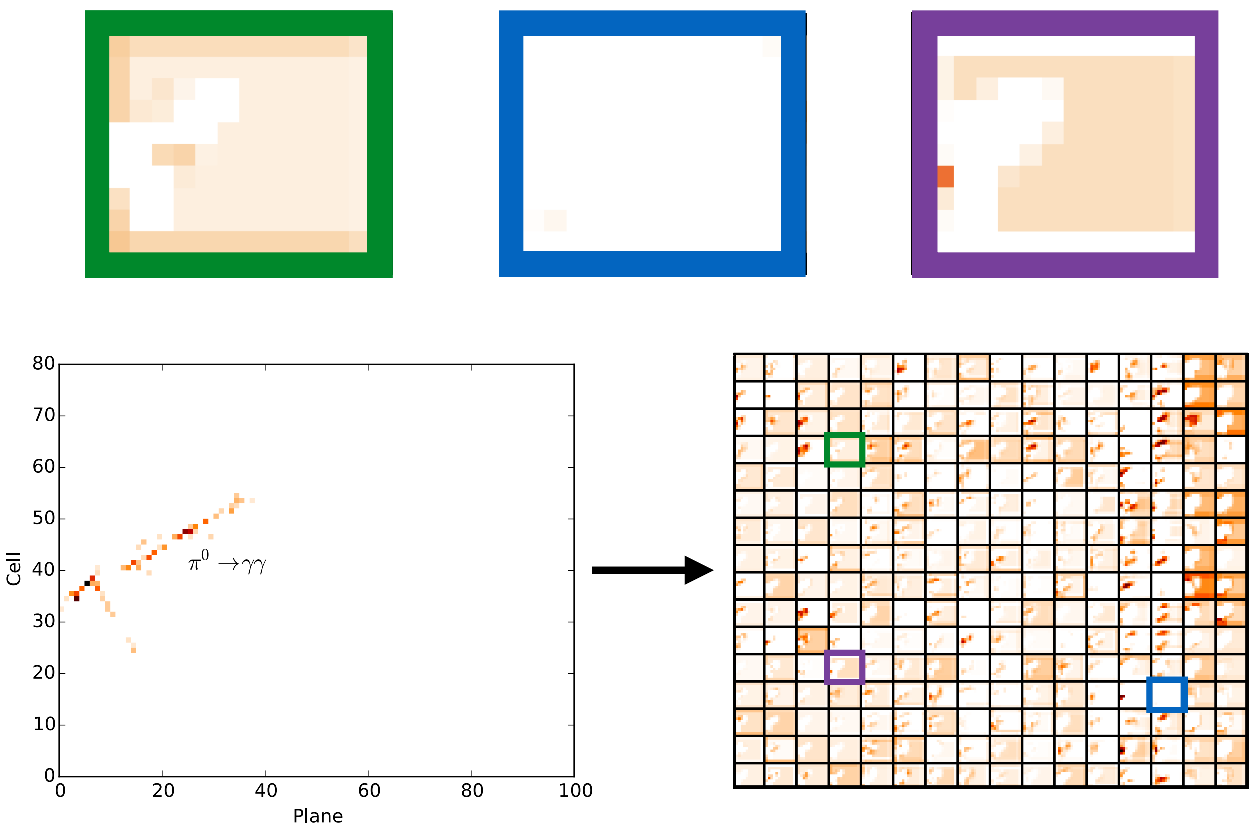
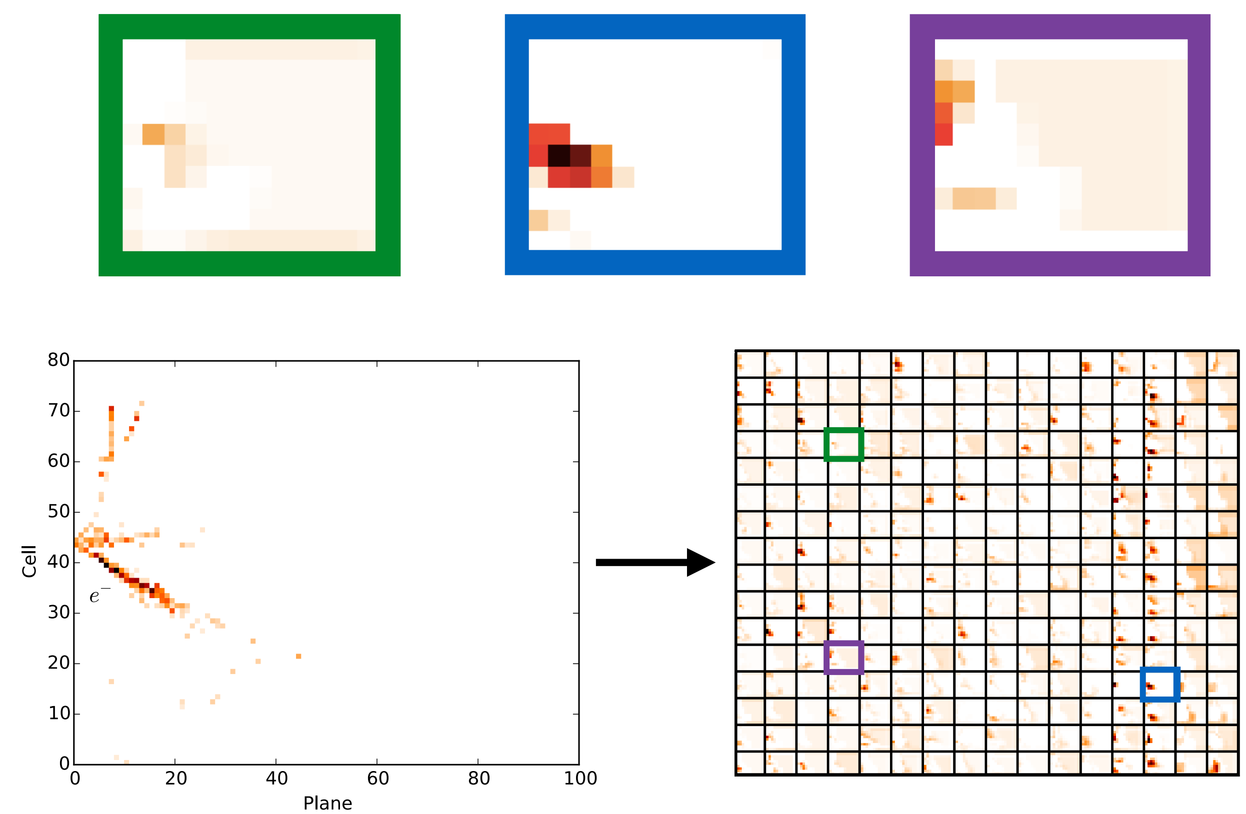
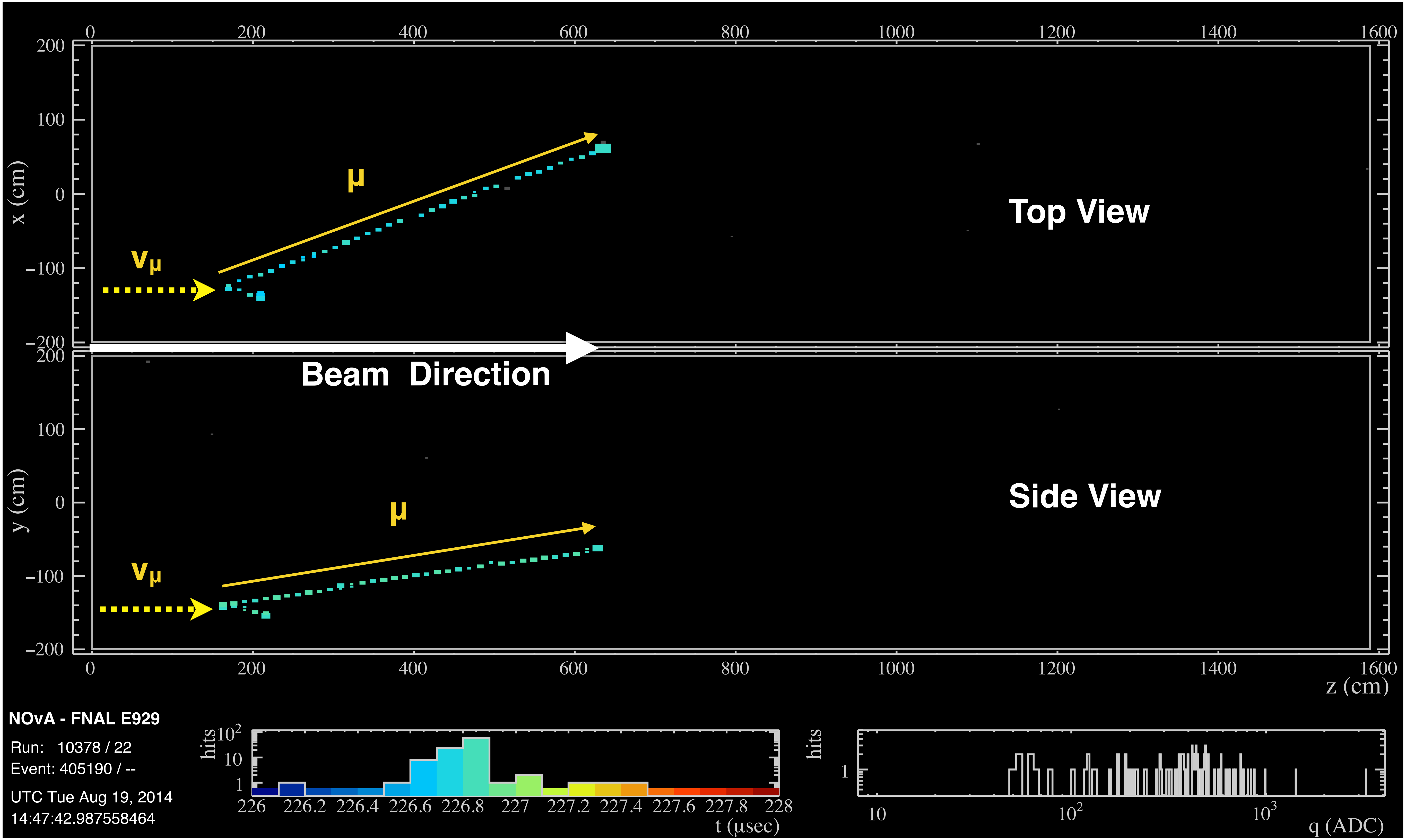


ν_e CC Event



Neutral Current

ν_μ Charged Current Event



NuMu CC Event Selection

- Developed a metric to select muon neutrino charge current events by minimization of systematic uncertainty.

$$\sigma = \frac{N_{sel} - N_{bkg}}{\epsilon N_{target}\Phi}$$

- Ignored statistical uncertainty and correlation between background counts and efficiency. Number of target is fixed. Also we have ignored flux as it is flat across energy.

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{N_{bkg}+(\delta N_{bkg}^{syst})^2}{(N_{sel}-N_{bkg})^2} + \left(\frac{\delta\epsilon}{\epsilon}\right)^2}$$

Fractional uncertainty on efficiency

statistical + systematic uncertainty on background.

Fractional uncertainty on cross-section

Uncertainties

The uncertainty can be accessed by comparison of modified MC with our nominal MC

Flux uncertainty determined from **P**ackage to **P**redict **F**lu**x** (**PPFX**)(~8 - 10%).
L. Aliaga et. al (MINERvA), Phys. Rev. D 94, 092005 (2016).

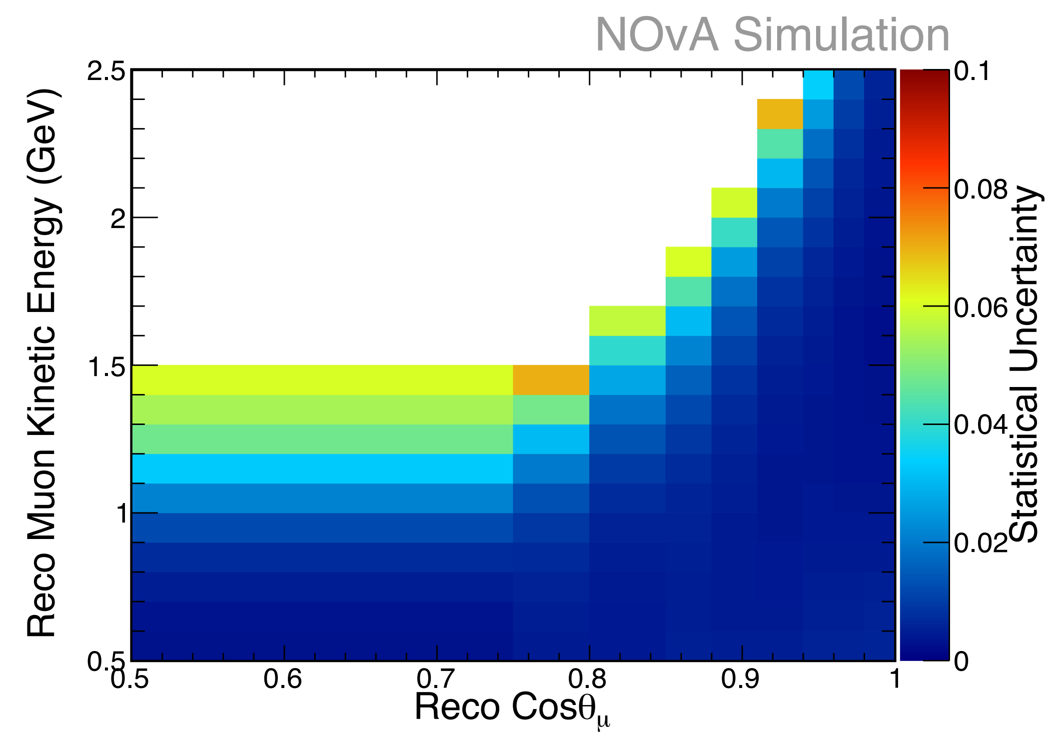
Using the PPFX package for the DUNE Experiment	*Amit BASHYAL*
Fermi National Accelerator Laboratory	14:24 - 14:42

Cross-section and Final State Interaction (FSI) uncertainty are determined using Genie re-weighting scheme

Hadronic energy uncertainty is 5%.

Detector response uncertainty.

Statistical uncertainty is very small,
< 1% for most of the bins.



NuMu CC Event Selection

$$\text{Efficiency} = \frac{\text{Total \# of selected true } \nu_\mu \text{ CC events}}{\text{Total \# of true } \nu_\mu \text{ CC events}}$$

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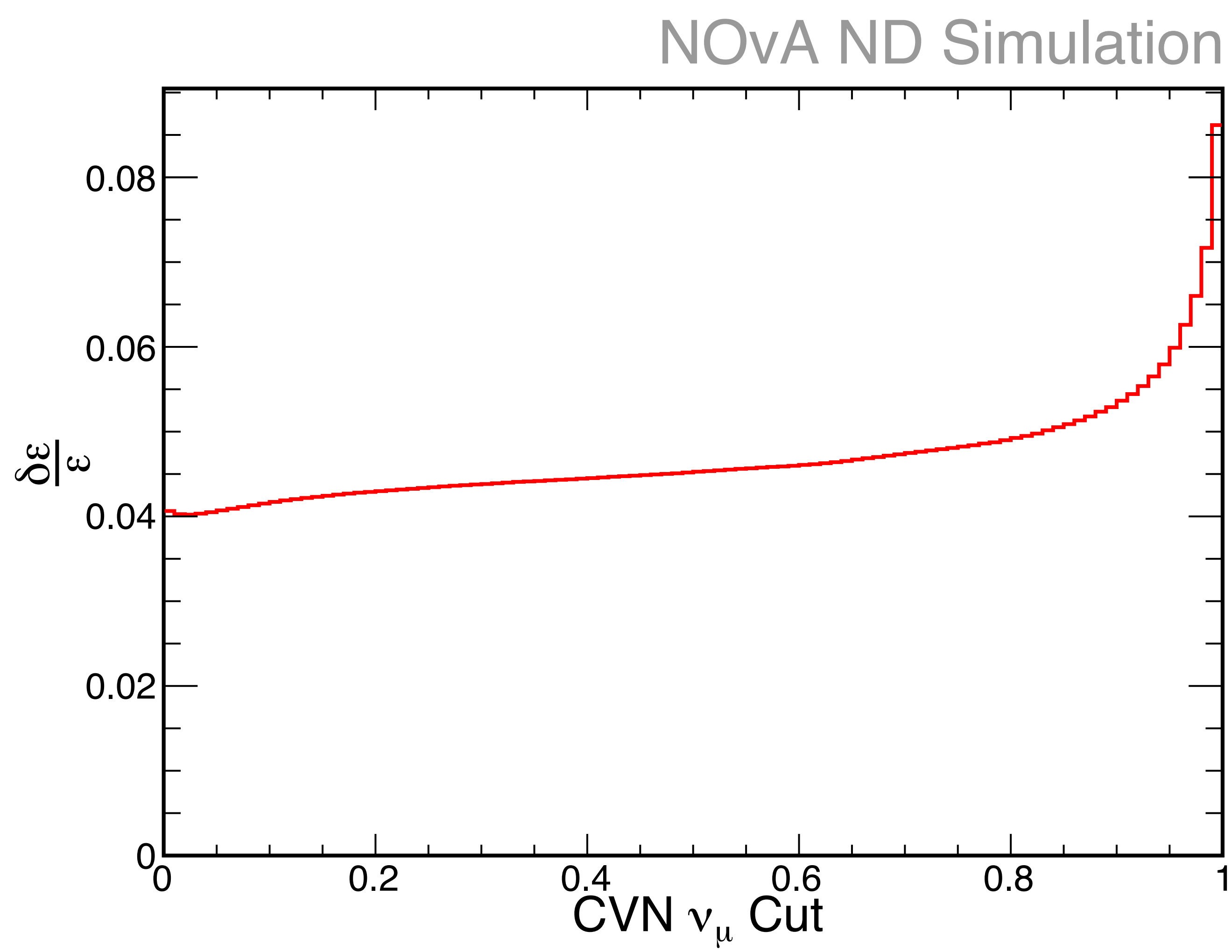

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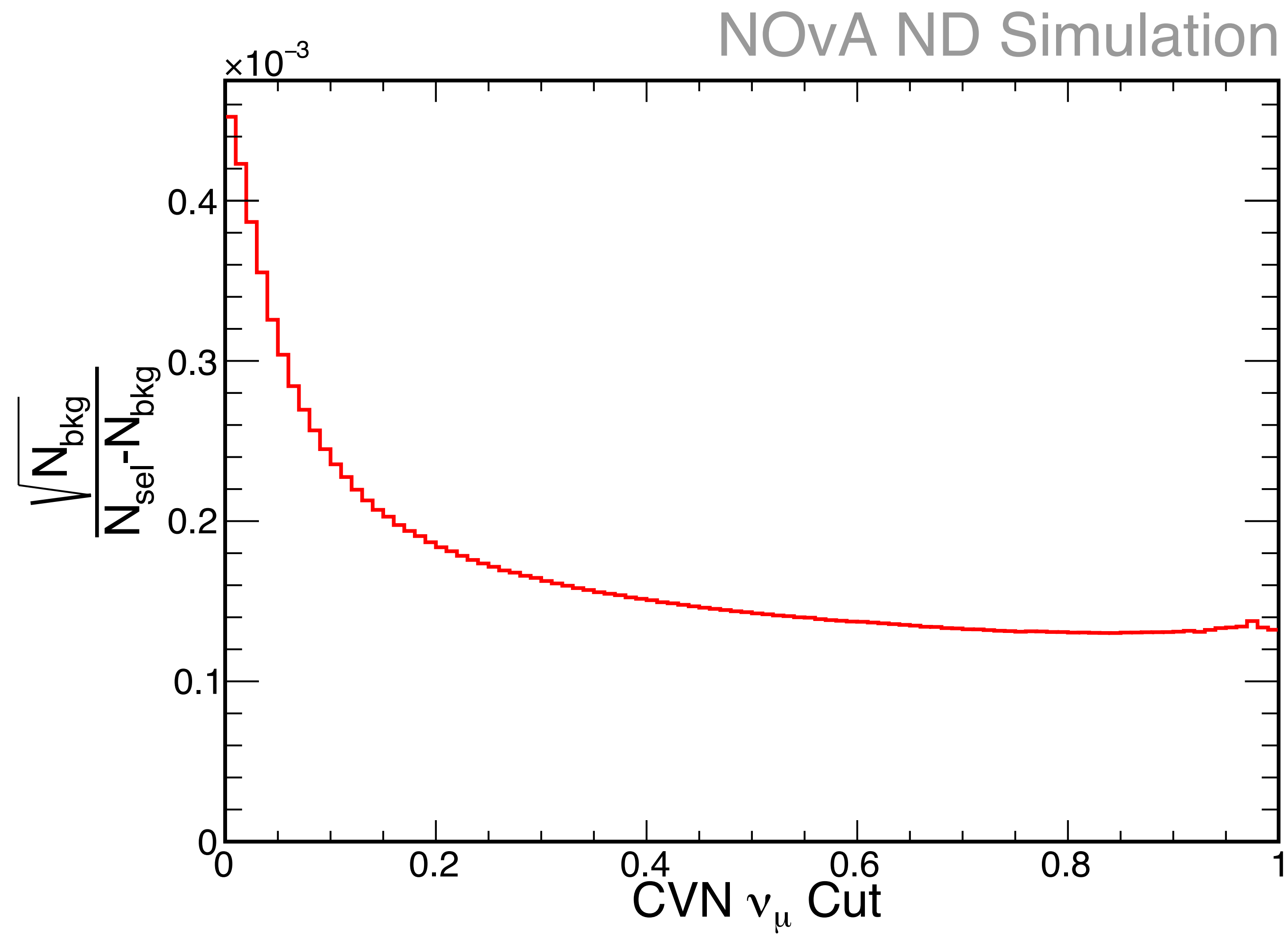

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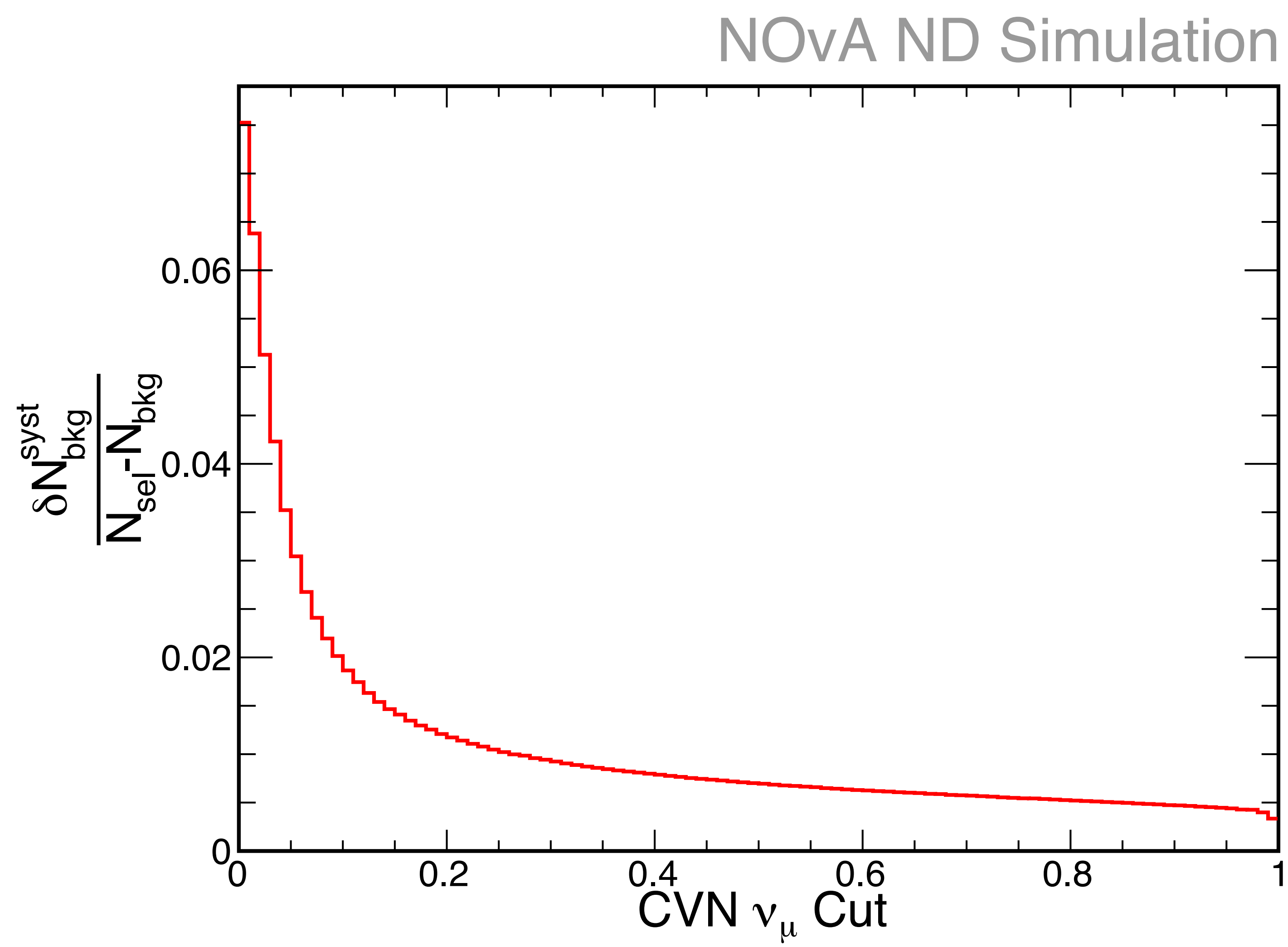

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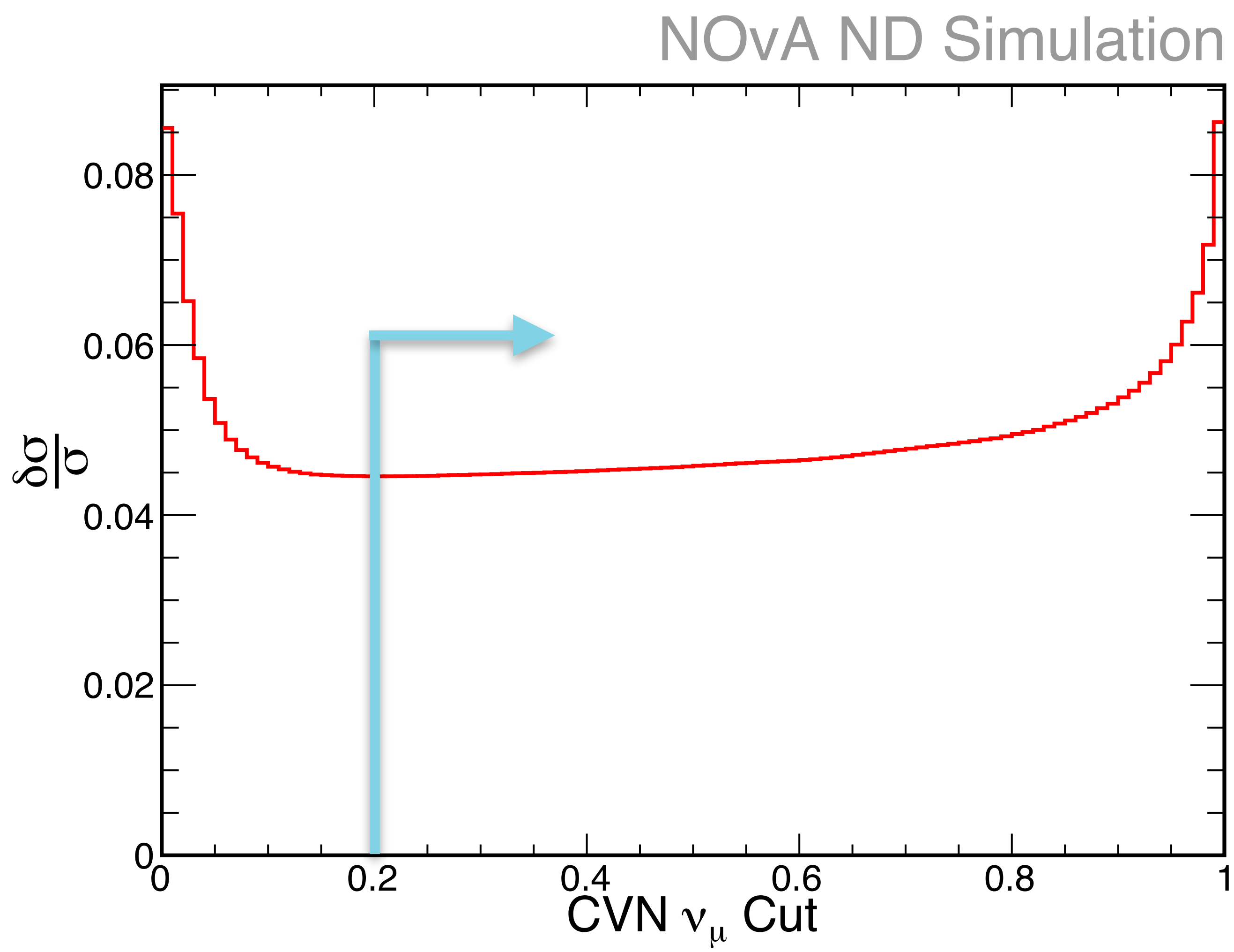
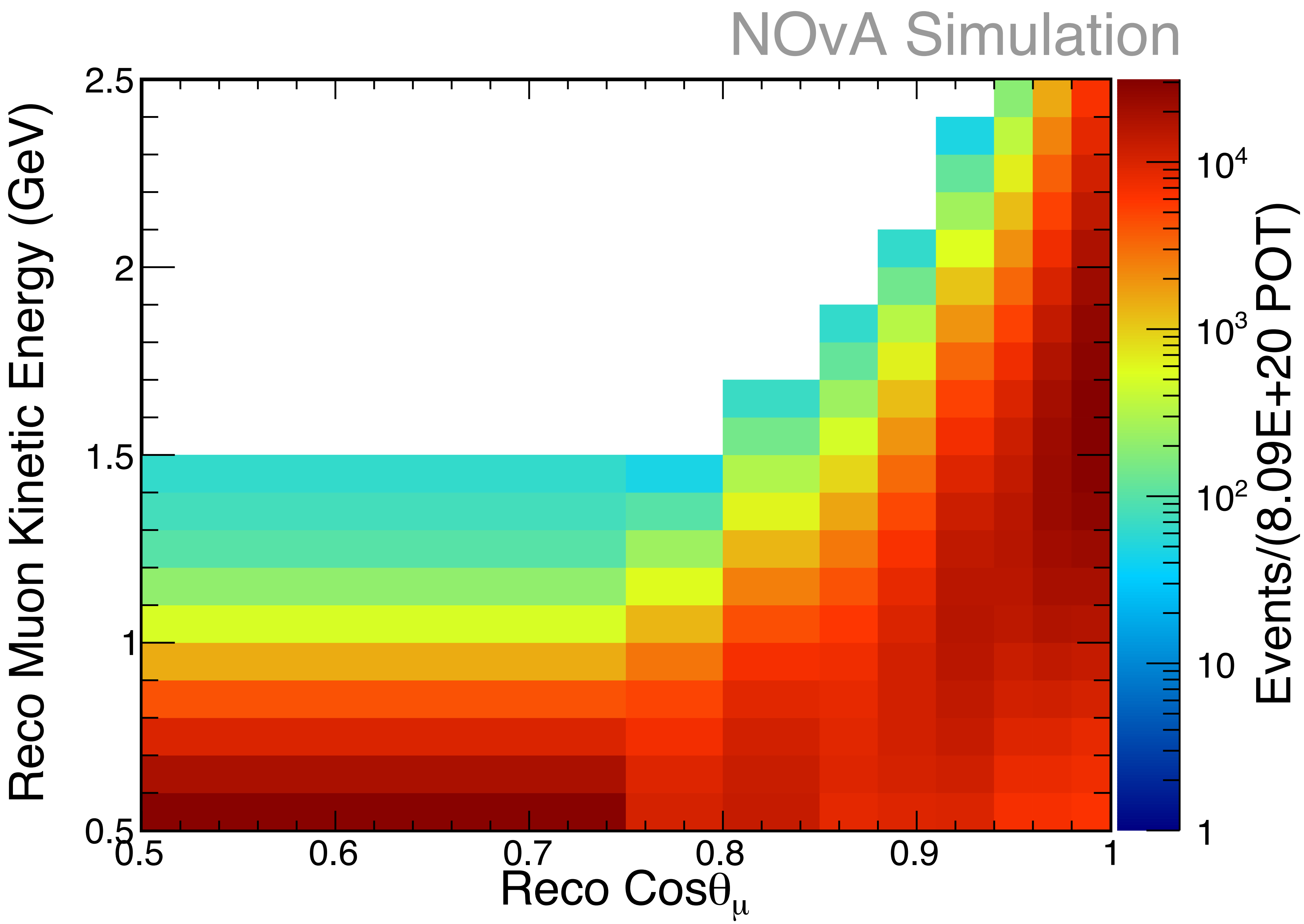


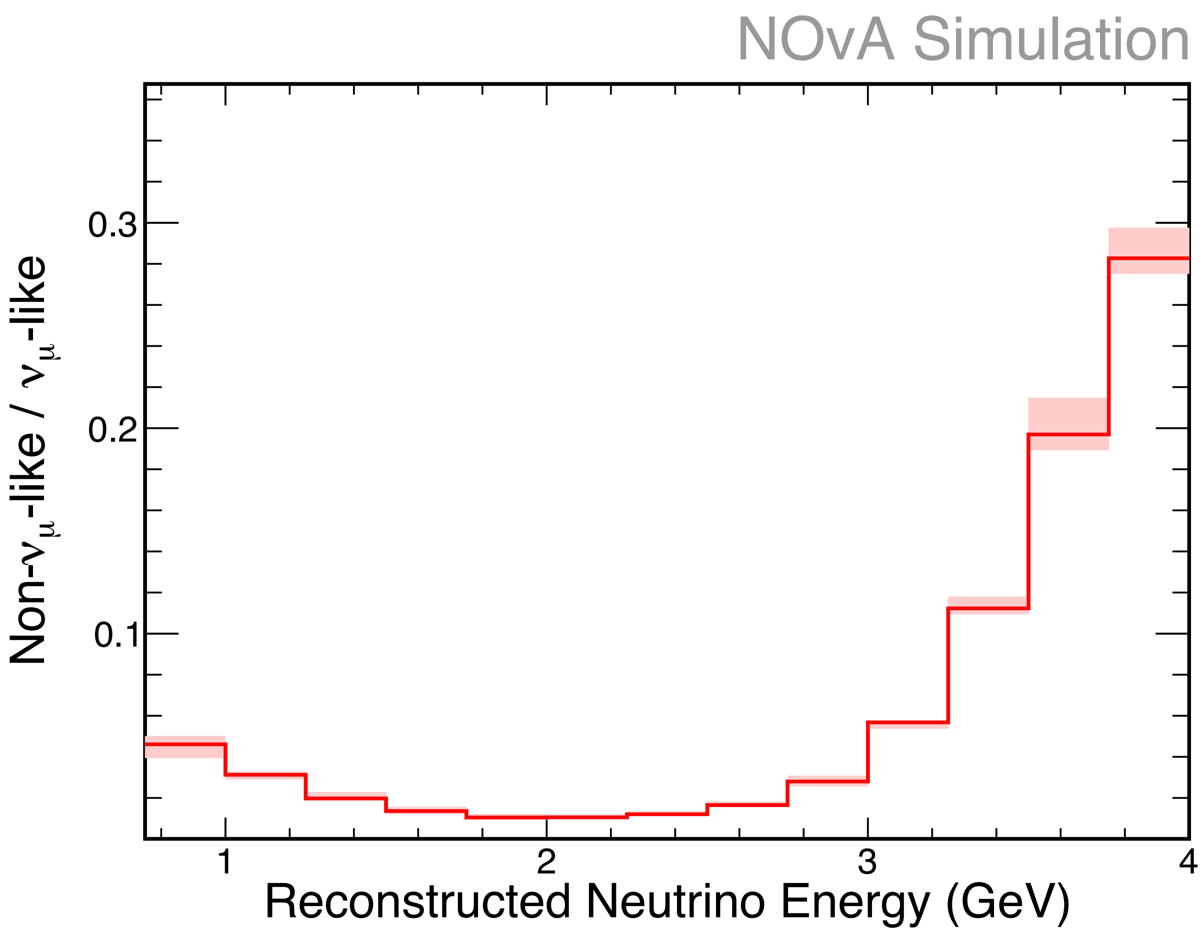
Events with CVN ν_μ > 0.2 are retained as candidate of ν_μ CC events.

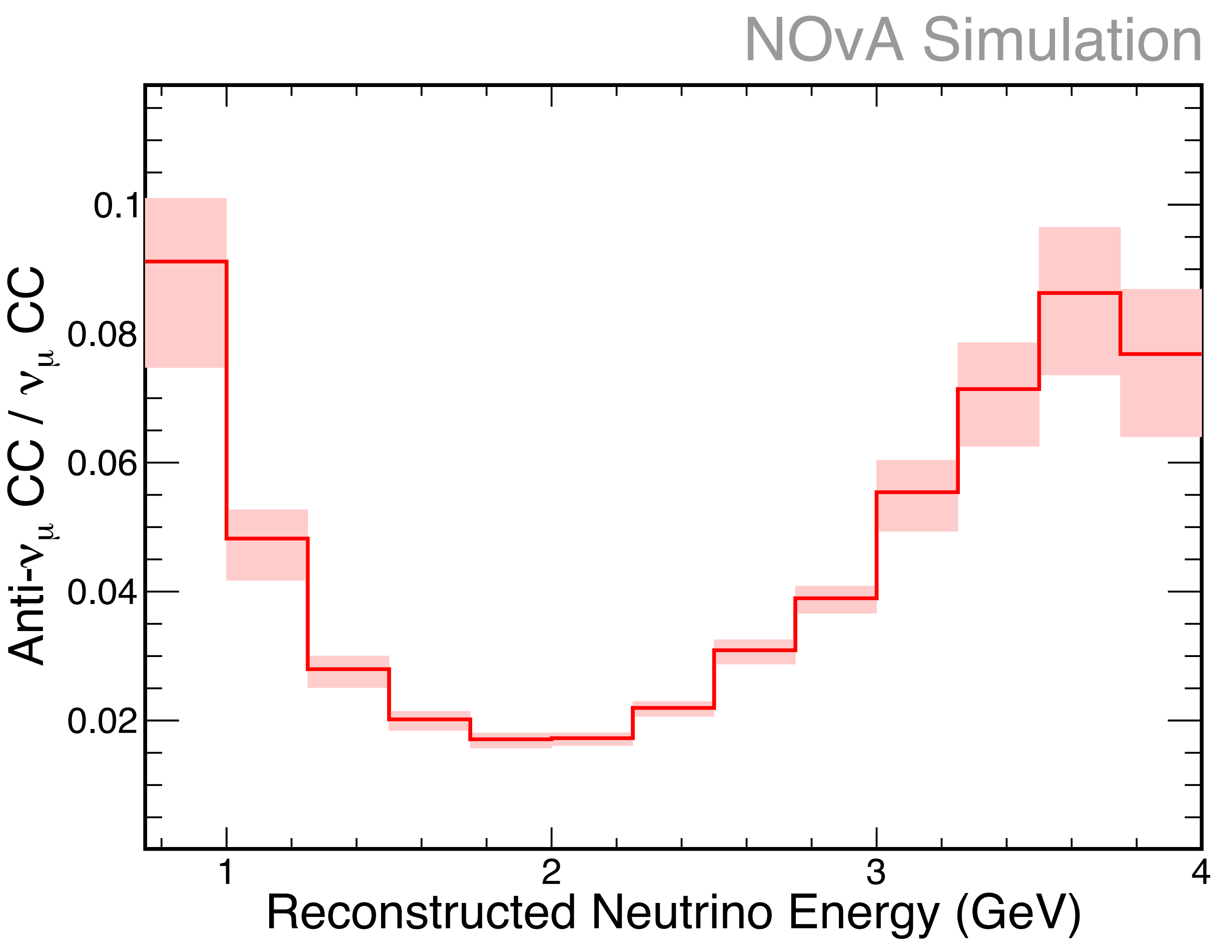
Kinematic Phase Space



Enough statistics allows us to do double differential cross cross-section in kinematic phase space.

Backgrounds





Backgrounds are small near the 2 GeV peak, larger in the tails of the spectrum. Dominant xsec and FSI systematics only shown here.

Wrong sign fraction as a function of reconstructed neutrino energy. Error band shows dominant flux systematic.

Uncertainties are at the level of a few %.

Summary and Future Plan

- NOvA has an excellent sensitivity to measure the cross-section in addition to neutrino oscillation study.
- Dominant Flux uncertainty is ~8-10%, Non-flux uncertainty is ~5%.
- We have taken another approach to select muon neutrino charge current events.
- Optimization of muon PID and estimation of neutrino energy is in progress.

Stay tune for exciting results!

Thank You

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